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RELATION AMONG MECHANICAL PROPERTIES OF GROUND GRANULATED BLAST FURNACE SLAG CONCRETE

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ABSTRACT

Ground granulated blast furnace slag (GGBS) is a well known pozzolanic material. In the present work, an attempt has been made to study the effect of GGBS inclusion on the fresh and hardened concrete properties (workability, compressive strength, flexural strength and split tensile strength), and to develop relationship among the different strength parameters. Eight concrete mixes containing 0, 10, 20, 30, 40, 45, 50 & 55% GGBS (weight basis) as cement (OPC) replacement were prepared to find the optimum replacement level of GGBS. M35 grade concrete with cement content of 460 kg/m^3 was used as a referral concrete. Test specimens were cured in tap water for 7, 28, 56, 90 days after the demoulding for compressive strength, while, the specimen for flexural and split tensile strengths were cured for 28 days only. This study shows that the workability increases with increase in the replacement level. The compressive strength, flexural strength and split tensile strength of concrete mixes increase with GGBS content till an optimum replacement level of 40%. Further addition, beyond this level shows a decrease in strength but still the strengths are generally more than the referral.

Key words: Compressive Strength, Flexural Strength, Split Tensile Strength, GGBS, Workability.

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1. INTRODUCTION

Now a days, a lot of attention is being paid on the selection of construction materials and their impact on environment. The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete. Unfortunately, production of OPC involves emission of large amounts of carbon-dioxide (approximately, 1Ton CO_2 /Ton of OPC production) gas into the atmosphere, a major contributor for green house effect and the global warming [1-3]. It is estimated that the emissions of CO_2 from OPC production worldwide is about 6-8% of the total global CO_2 emission [4-6]. So, it is need of the time to search alternative main binder or supplementary cementitious material (SCM) without compromising the properties of concrete, environment and natural resources. Such materials, which can be used as SCM should lead to global sustainable development and lowest possible environment impact [7-9]. Fly ash (FA), ground granulated blast furnace slag (GGBS), rice husk ash (RHA), high reactive metakaoline and silica fume (SF) are some of the pozzolanic materials/SCM, which can be used in the concrete for the partial replacement of cement. A number of studies are going on in India as well as abroad to study the impact of SCM for part replacement of OPC in concrete. These SCM not only enhance the mechanical properties of concrete but also improve the pore structure of concrete. GGBS is one of the SCM [10]. It is a byproduct obtained from the blast furnaces used to produce Iron. Jin and Li [11] reported that the mechanical properties of young concrete (less than an age of 7 days) play an important role in determining construction speed and quality, especially for high rise buildings and nuclear power plants. A better understanding of the mechanical properties of young concrete is essential to make a right decision during the construction stage. However, it is usual to take the 28-days compressive strength as index of concrete quality. Hooton and Emery [12] reported that the properties of GGBS influence the glass content, chemical composition, mineralogical composition etc of concrete. Swamy and Bouikni [13] reported that, by a proper mix proportioning, GGBS concrete can be produced with strengths comparable to those with OPC from 3rd day onwards. Authors proposed that the total cementitious material is to be increased by 10% for 50% replacement of OPC by GGBS, and by 20% for 65% replacement to attain strengths comparable to normal concretes. Ganesh Babu *et al* [14] observed that for obtaining equal strength in concretes at 28 days, an additional 8.5% and 19.5% increase in the total cementitious materials is required for50% and 65% OPC replacement levels.

Oner and Akyuz [15] observed that on increasing the GGBS inclusion, the water-to-binder ratio decreases for the same workability. Also, it is observed that the early age strength of GGBS concrete was lower than the control concrete with the same binder content. However, as the curing period is extended, the strength increase was higher for the GGBS concrete. They explained that the pozzolanic reactivity was slower at early age because of the late release of calcium hydroxide. The compressive strength of GGBS concrete increases as the GGBS content is increased up to an optimum point, after which the compressive strength decreases. The optimum level of GGBS content for maximizing strength is about 55–59% of the total binder content. Wu *et al* [16] studied the effect of GGBS and flyash content on the compressive and flexural strengths of Ultra high performance concrete (UHPC). Authors reported that flowability of concrete increases with inclusion of GGBS in UHPC. Authors

also reported that the addition of GGBS in concrete had limited influence on compressive strength; however, the flexural strength increases with replacement of OPC with GGBS upto 40%.

The relation between the flexural strength (f_{cr}, MPa) and characteristic compressive strength (f_{ck}, MPa) is given in IS:456-2000 [17] in the form of Eq. 1:

$$f_{cr} = 0.7\,(f_{ck})^n \qquad (1)$$

where, coefficient n=0.5 for OPC concrete

A number of empirical formulae showing the relation between the splitting tensile strength (f_t, MPa) and compressive strength of cylindrical specimen (f_c,MPa)) are suggested by many investigators. The general form is given as Eq.2:

$$f_t = k\,(f_c)^n \qquad (2)$$

where, k and n are coefficients.

The values of n suggested by different investigators to lie between ½ and ¾. The former value is used by the American Concrete Institute (ACI); however, Gardner and Poon [18] found the value nearer to the latter. Raphael [19] suggested the following expression (Eq. 3) relating the tensile strength and compressive strength.

$$f_t = 0.3(f_c)^n \qquad (3)$$

where, n = 2/3

Later, Oluokun [20] modified Eq. 3, and suggested the following expression (Eq. 4):

$$f_t = 0.2(f_c)^n \qquad (4)$$

where, n = 0.7.

In this paper, the results of an experimental investigation carried out to find the: i) effect of GGBS inclusion on the fresh concrete property i.e., workability; ii) optimum dose of GGBS as partial replacement of OPC in concrete, in respect of mechanical properties of hardened concrete (compressive, flexural and split tensile strengths) are presented.

2. MATERIALS AND MIX PROPORTIONING

The concrete mix was designed using JAYPEE 43-grade OPC confirming to IS: 8112-1989 [21]. The specific gravity, soundness and fineness (90µ sieve) were 3.15, 2.0 mm and 4.0%, respectively. The GGBS was procured from FINESSE SCM Pvt. Ltd. Mumbai (India). The physical properties and chemical composition of GGBS are given in Table 1. The fine and coarse aggregates were procured form the local quarries. Coarse aggregate of size 10 mm having specific gravity and fineness modulus of 2.65 and 6.26, respectively was used. The specific gravity and fineness modulus of fine aggregate were 2.71 and 2.05, respectively. The aggregates confirmed to the requirements of IS: 383-1970 [22]. The water absorption of coarse aggregate and fine aggregates were 0.47% and 0.90%, respectively. The volume percentage of fine aggregate to the total volume of aggregate was kept 32% in all the mixtures. Polycarboxylic Ether based super plasticizer 'GLENIUM', procured from BASF (India) was used in this investigation. The referral concrete of M-35 grade with OPC content of 460 kg/m^3 was used, and it was designed as per SP: 23 – 1982 [23] and IS: 10262-2009 [24]. The resulting mix proportion of cement: fine aggregate: coarse aggregate was 1:1.24:2.58 with water cement ratio of 0.40. The different mixes of concrete were prepared using GGBS for partial replacement of OPC, and the replacement levels varied were 10, 20, 30, 40, 45, 50 and 55 % by weight of OPC. Water to binder ratio of 0.40 and air content of 2% was kept constant in all the mixtures. The super plasticizer (1 % by the weight of binder) was added to maintain the workability over 100 mm in all the mixes. The Plain Cement Concrete (PCC) cubes(referral) of 100 mm size for compressive strength, 100x100x500 mm

specimens for flexure test, and cylindrical specimens of 100 mm diameter and 200 mm height for split tensile test were cast, and demoulded after 24 hours, and put in tap-water for curing. The vibration table was used for compaction of the concrete. Abram's cone apparatus was used to determine the slump of different mixes. The mix proportioning and slump of different mixes are given in Table 2. Compression test was conducted on a 2000 kN 'AIMIL' compression testing machine. Load was applied as per IS: 14858-2000 [25] and IS: 5816-1999 [26] for compressive strength and split tensile strength, respectively. Hydraulic Jack of capacity 250 kN was used for flexural strength test, and the load was applied as per IS:516-1959 [27]. For each mix of the concrete, the compressive strength of the hardened concrete was found at 7, 28, 56 and 90 days of the curing. The split tensile strength and flexural strength of all the mixes were determined after 28 days of curing.

Table 1 Physical and Chemical Properties of GGBS

Colour	Specific Gravity	Specific Surface Area	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	LOI (%)
White	2.92	4250 cm^2/gm	39.18	10.18	2.02	32.82	8.52	1.14	0.30	< 1.0

Table 2 Mix Proportioning and Slump of different concrete mixes

Replacement level (%)	**Cement (kg)**	**GGBS (kg)**	**Water (Litre)**	**CA (kg)**	**FA (kg)**	**Slump (mm)**
0.0	460	0	184	1187	570	105
10.0	414	46	184	1187	570	108
20.0	368	92	184	1187	570	110
30.0	322	138	184	1187	570	114
40.0	276	184	184	1187	570	116
45.0	253	207	184	1187	570	120
50.0	230	230	184	1187	570	122
55.0	207	253	184	1187	570	125

3. RESULTS AND DISCUSSIONS

3.1. Properties of Fresh Concrete

The mix proportioning of concrete and slump of different concrete mixes are given in Table-2. It is evident from Table-2 that the workability of concrete mixes is increases from 105 mm to 125 mm on increasing the GGBS inclusion (0 to 55 %). An increase in the slump of concrete mixes on increasing the GGBS content is also reported [15 &16]. This may be due to the lesser specific surface area and spherical particles character of GGBS.

3.2. Compressive Strength of Different Concrete Mixes

The compressive strength of the different GGBS concrete mixes obtained at 7, 28, 56 and 90 days of curing is plotted in Fig. 1. It is observed from this figure that the strength gain is a function of time. The addition of GGBS improved the compressive strengths at all the ages. The strength is increased even at 55% replacement leve,l but the maximum strength gain is obtained at the 40% replacement level(Optimum). At optimum replacement level, the increase in strength is found to be 16.85%, 9.19%, 14.95% and 25.6% at the age of 7, 28, 56 and 90 days, respectively, as compared to the referral sample. Oner and Akyuz [15] reported the optimum level of replacement as 55-59%, however, Wu *et a*l [16] reported replacement upto 40%, without much influence over the compressive strength. In the present investigation, the optimum level at lower percentage may be due to better glass content,

chemical composition and mineralogical composition of GGBS. Further the compressive strength of GGBS added concrete is more than the referral concrete at 7 days (Fig.1). This may be beneficial in construction activities, where young concrete plays an important role.

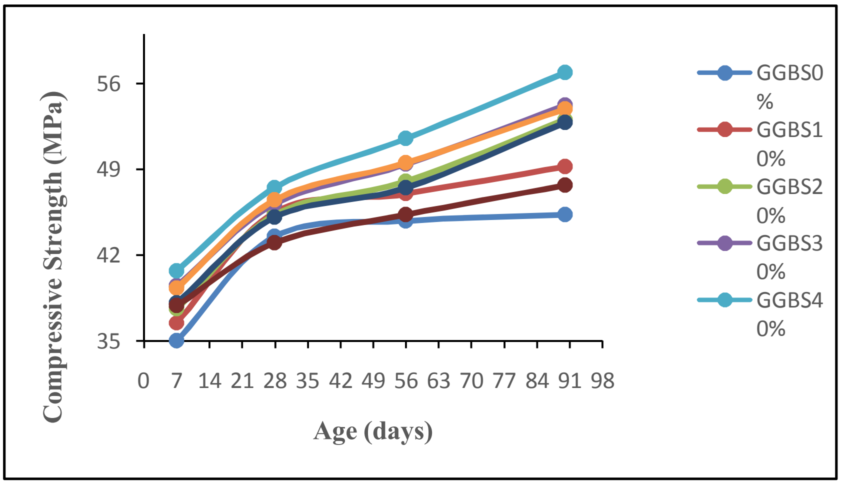

Figure 1 Variation of Compressive Strength of GGBS Concrete with age at different replacement levels

3.3. Flexural Strength of Different Concrete Mixes

The inclusion of GGBS also brought marginal improvement in flexural strength of concrete. The flexural strength results obtained at the age of 28 days are listed in Table 3.The maximum improvement in flexural strength is found at 40% replacement level and the increase is 18.75% as compared to the referral; however, beyond that level the improvement is not much. The ratio of flexural strength to compressive strength at 28 days is almost similar in all the mixes and is in the range of 18.39 - 20.12%. The optimum replacement level (40%) is similar to finding of Wu *et al* [16].

Table 3 Value of coefficient 'n' in the relation between Compressive and Flexural strengths of different Concrete Mixes.

Replacement level (%)	Compressive Strength at 28 days(MPa) (Size 100x100x100)	Flexural Strength at 28 days (MPa) (Size 100x100x500)	Value of 'n' From Eq.1
0.0	43.5	8.0	0.645
10.0	44.5	8.5	0.657
20.0	45.3	8.9	0.666
30.0	46.2	9.3	0.674
40.0	47.5	9.5	0.675
45.0	46.5	9.1	0.668
50.0	45.1	8.4	0.652
55.0	43.0	8.1	0.650

3.4. Relation between Compressive Strength and Flexural Strength

The results obtained in the present investigation were plotted to get a relation between flexural and compressive strengths (Fig. 2). The relation obtained is given as Eq. 5:

$$Y = 0.349X - 7.047 \quad \text{with } R^2 = 0.908 \qquad (5)$$

where, Y (f_{cr}) = Flexural strength of concrete specimen of size 100x100x500 mm (MPa),

X (f_{ck}) = Characteristic compressive strength of 100mm concrete cube (MPa)

The flexural (f_{cr}) and compressive strength (f_{ck}) values obtained for the different concrete mixtures were fitted in Eq.1. The value of coefficient 'n' for GGBS concrete was obtained in the range of 0.645 -0.675 (Table-4), instead of 0.5 suggested by IS code for OPC concrete, and its standard specimen sizes. The maximum value of 0.675 was found at 40% replacement. This increase in coefficient 'n' may be due to marginal increase in ductility of concrete mixes due to the inclusion of GGBS.

Table 4 Values of 'n' in the relation between Split Tensile and Compressive Strengths of different Concrete Mixes.

Replacement level (%)	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Value of 'n'	
	28days	28 days	From Eq. 3	From Eq. 4
0.0	43.5	3.85	0.676	0.784
10.0	44.5	3.92	0.677	0.783
20.0	45.3	4.12	0.687	0.793
30.0	46.2	4.41	0.701	0.807
40.0	47.5	4.93	0.725	0.830
45.0	46.5	4.52	0.706	0.812
50.0	45.1	4.15	0.689	0.796
55.0	43.0	3.81	0.675	0.783

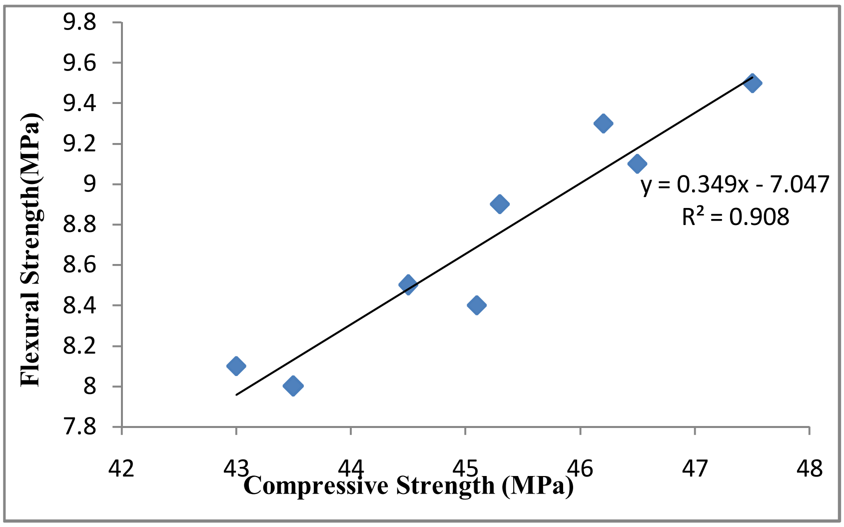

Figure 2 Relation between flexural and compressive strengths of different concrete mixes at 28 days

3.5. Split Tensile Strength of Different Concrete Mixes

The results of split tensile strength of different concrete mixes are given in Table-4. The split tensile strength of mixes was found to increase upto 40% replacement level, and thereafter, a decreasing trend was observed. However, strength was found to be more than the referral concrete upto the replacement level of 50.0%. The split tensile strength of mix at 40% replacement level is 24.06% more than the referral concrete. The ratio of split tensile strength to compressive strength of different mixes at 28 days is almost similar, and lies in the range of 0.087-0.104. The optimum replacement level of 40% may be used for structural purposes, after studying the mineral composition of GGBS.

3.6. Relation between Compressive Strength and Split Tensile Strength

For developing a relation between the split tensile strength and compressive strength results from this investigation, a best fit curve (Fig. 3) was drawn. The relation obtained is given as Eq. 6:

$$Y= 0.243X-6.796 \text{ with } R^2= 0.925 \qquad (6)$$

Where, Y (f_t) = Splitting strength of cylindrical concrete specimen of size 100x200 mm (MPa), X (f_{ck}) = Compressive strength of 100mm cube specimen of concrete (MPa).

The result of split tensile (f_t) and compressive strength (f_{ck}) obtained for the different concrete mixtures were fitted in Eqs. 3 and 4. The value of 'n' obtained in the present investigation with referral concrete is 0.676 (Table-4), which is similar to the results of Gardener and Pool [18]. However, when GGBS replacement level varies between 10-55%, the value of 'n' varies in the range of 0.675-0.725 (Table-4), which is slightly higher than the referral concrete. The maximum value of 0.725 was found at 40% replacement. Again, using Eq. 4, the value of 'n' obtained from the results of the present investigation for referral concrete is found to be 0.784 (Table-4), which is higher than that obtained from Eq. 4. However, the value of 'n' varies in the range of 0.783-0.830 (Table-4), when GGBS replacement level varies between 10-55%. The maximum value of 'n' was found to be 0.830 at 40% replacement. So, the relation between compressive strength and split tensile strength is very close to Eq. 3, and there is a significant deviation from Eq. 4. The higher value of 'n' may be due to improved pore structure of the concrete after inclusion of GGBS.

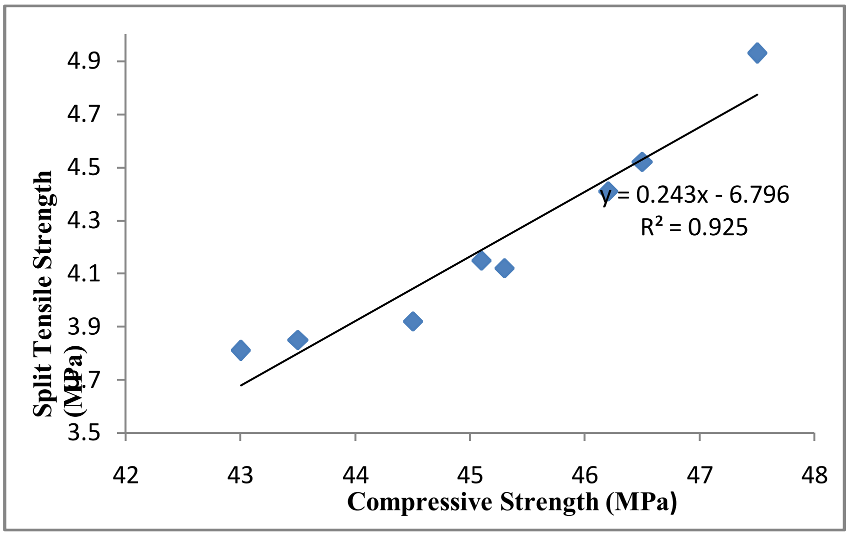

Figure 3 Relation between split tensile and compressive strengths of different concrete mixes cured at 28 days.

4. CONCLUSIONS

The following conclusions can be drawn from this study.

- The workability of mixes is increased on part replacement of OPC by GGBS and depends on the replacement level.
- The mechanical properties viz., compressive strength, flexural strength and split tensile strength, in general, increases at all the replacement level, except the split tensile strength which decreases at a level of 55%. The optimum replacement level is 40% for structural purposes.
- At the replacement level of 40%, the gain in compressive strength at the ages of 7, 28, 56 and 90 days is found in the range of 9.19-25.6% as compared to referral concrete.

- At the optimum replacement level of 40%, the gain in flexural and split tensile strengths at the age of 28 days is 18.75% and 24.6%, respectively, as compared to the referral concrete.
- The value of ‘n’ obtained is higher in case of GGBS concrete in comparison to the value of ‘n’ suggested for relation between flexural strength and compressive strength (Eq.1).
- The value of ‘n’ obtained for different mix proportions is slightly higher than the value of ‘n’ suggested by Eq. 3 for relation between split tensile strength and compressive strength. However, it is significantly higher at optimum replacement level of 40%.
- The value of ‘n’ found in the present investigation is significantly higher than those suggested in Eq. 4. So these results do not fit in Eq. 4.
- The increase in ‘n’ values shows that the GGBS concrete is more ductile than referral concrete.
- Flexural strength of GGBS concrete may be estimated by using the Eq.5.
- The split tensile strength of GGBS concrete may be estimated by using the Eq.6.

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